The NOvA Experiment at Fermilab

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Abstract. The NOvA (NuMI Off-axis ν_e Appearance) experiment is the latest of the long-baseline neutrino oscillation experiments with L/E ~ 400 GeV and atmospheric Δm^2 and the flagship experiment at Fermi National Accelerator Laboratory (FNAL) from next year on. It consists of two, functionally identical detectors, of 200 and 14k tons respectively, that are positioned 14mrads off-axis of the NuMI ν_μ-beam and 810 km apart. It has the means to measure the θ_{13} with an order of magnitude better than the current limits and the potential to resolve the mass hierarchy if combined with other world measurements from accelerator and reactor experiments. The NDOS prototype is a functional detector system at FNAL and has proved the NOvA technology.

Motivation

Precise measurements of oscillation parameters can provide a valuable check as to whether they are the solution to neutrino anomalies:

- Although the PMNS matrix is analogous to CKM matrix, why is the lepton sector mixing much larger than quark sector mixing?
- Why is there the sequence: θ_{23} maximal, θ_{12} moderately large, θ_{13} very small or zero?
- Is there a CP violation in the lepton sector? If so, then how large?
- Since the neutrino mass is rather small, does this suggests a heavy partner?
- Establishing an inverted hierarchy indicates that for the next generation of 0νββ searches an absence of observation will mean that neutrinos are Dirac particles.

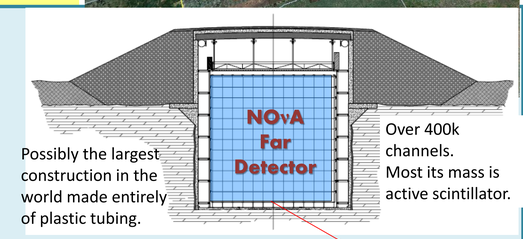
NOvA Physics Goals

Search of $\nu_\mu \rightarrow \nu_e$.
Measurement and limit of θ_{13}.
Determination of mass hierarchy.
Constraint of CP violation phase(δ).
Precise measurement of
$|\Delta m^2|$ and θ_{23}.
Comparison of ν and $\bar{\nu}$ oscillations.

NOvA Technology

Finely-segmented tracking-calorimeter.
Same detectors (Far-Near) to reduce systematic uncertainty.
A 14kton Far detector with 65% active volume for gamma containment.
Low Z (0.15 Xo per layer) for PVC extrusions + Liquid Scintillator+ mineral oil + 5% pseudo-cumene.
Layered planes orthogonally-oriented cells.
Read out via WLS fiber to APD.
State-of-the-art DAQ & DCS from FNAL.

D. S. Ayres el al., The NOA technical design report, Fermilab-Design-2007-01(2007).



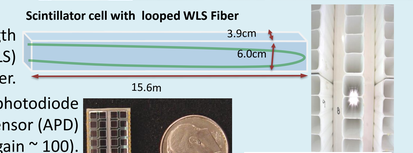
Possibly the largest construction in the world made entirely of plastic tubing.

Over 400k channels. Most its mass is active scintillator.

The Far Detector Today

The FAR Detector Building entrance.

Scintillator cell with looped WLS Fiber



Wave length shifting (WLS) fiber.

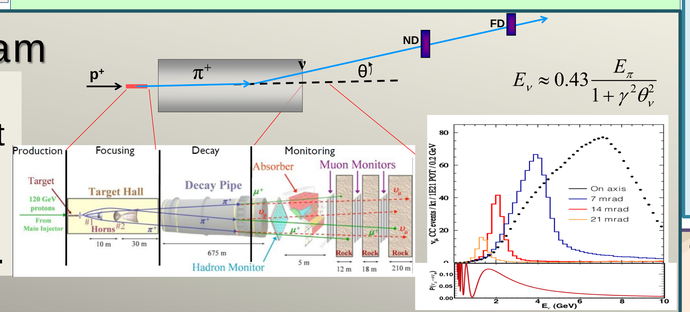
Avalanche photodiode photo-sensor (APD) (-15C, gain ~ 100). Custom electronics readout.

Low Z extrusions, in alternating x-y layers.

The NuMI Beam

Upgraded from the MINOS era:
700kW power.
12 Booster batches.
High power target.
High energy Horn.

Off-axis by 14mrad.
Narrow-band: peak at 2 GeV.
Near oscillation max.
Less NC background.



$$E_\nu \approx 0.43 \frac{E_\pi}{1+\gamma^2\theta_\nu^2}$$

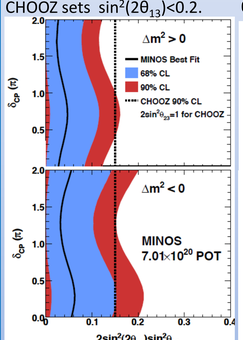
http://www-nova.fnal.gov/nova_beam_anu.html

Current Limits

MINOS &CHOOZ

http://www-numi.fnal.gov/Minos/

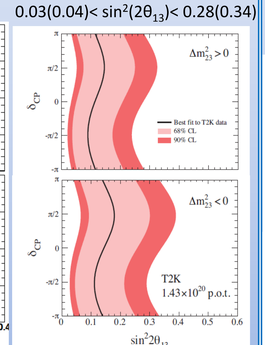
MINOS reported 2σ difference between best fit values for neutrinos and antineutrinos. CHOOZ sets $\sin^2(2\theta_{13})<0.2$.



Double CHOOZ will explore the range of $\sin^2(2\theta_{13})$ from 0.2 to 0.03, within three years of data taking.
http://doublechooz.in2p3.fr/

Latest from T2K (2011)

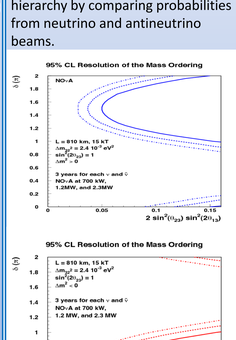
For $\delta_{CP} = 0$ and normal (inverted) hierarchy at 90% CL.
$0.03(0.04) < \sin^2(2\theta_{13}) < 0.28(0.34)$



Phys. Rev. Lett. 107, 041801 (2011)
http://www.t2k.org/

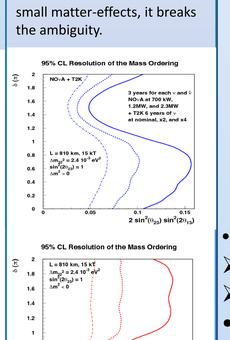
NOvA alone

Simulation predictions of the hierarchy resolution for CP-phase >π. It can resolve the the mass hierarchy after 3 years ($18*10^{20}$ PoT) each of neutrino and antineutrino beam in both normal and inverted hierarchy by comparing probabilities from neutrino and antineutrino beams.



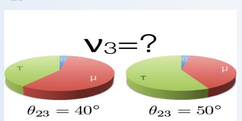
NOvA & T2K

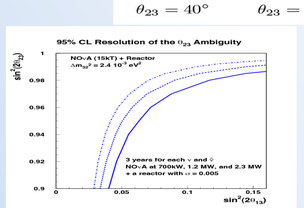
If the phase is such that it does not allow NOvA to resolve the hierarchy on its own, then combining its measurement with the heavy matter-effect with the ones of T2K with the small matter-effects, it breaks the ambiguity.



NOvA &Reactor Experiments.

The quadrant of θ_{23}





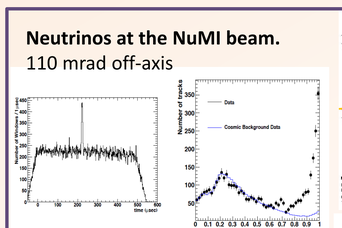
- Long baseline experiments measure:
  - $\sin^2(2\theta_{23})$and
  - $2\sin^2(\theta_{23})*\sin^2(2\theta_{13})$
- Reactor experiments measure:
  - $\sin^2(2\theta_{13})$ without θ_{23}
- Combination allows for resolving the ambiguity of $\sin^2(2\theta_{23})$ and $\sin^2(\theta_{23})$

The present: Near Detector on the Surface **NDOS**

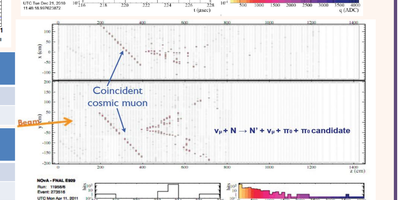
Prototype detector.
- 110mrad off-axis to NUMI.
- On-axis to BNB 23° turned.

NDOS Goals:
- Test detector design and installation procedures.
- Exercise calibration scheme.
- Benchmark MC.
- Demonstrate electron neutrino selection.
- Background suppression.
- Verify cosmic background suppression.
- Study nuclear hadronization models.
- Quasi-elastic cross section at 2 GeV.
- Constrain neutrino flux.
- Booster short-baseline oscillations.

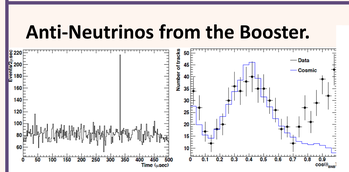
Neutrinos at the NuMI beam.
110 mrad off-axis



Reverse Horn Current Mode 5.6 x 10^{19} POT	NuMI ν's	BG
Fiducial Events	1001	69
Fully Contained	184	12
Forward Horn Current Mode 8.4 x 10^{18} POT	**NuMI ν's**	**BG**
Fiducial Events	253	39
Fully Contained	36	12



Anti-Neutrinos from the Booster.



Detector is on the Booster neutrino beam axis
Detector axis rotated ~20° relative to the beam axis
$3x10^{19}$ POT reverse horn current beam, 222 booster events (92 cosmic BG)